IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Application of Bateman et al.	)
	) Group Art Unit: N/A
	)
Serial Number 10/693,874	) Examiner: N/A
	)
Filed October 28, 2003	) Atty Docket: DEH071

For: Mass Spectrometer

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Respectfully Submitted,
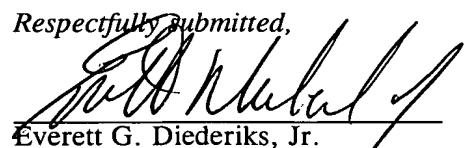
Everett G. Diederiks, Jr.
Attorney for Applicant
Registration Number: 33,323

Date: December 17, 2003

The Patent Office
Concept House
Cardiff Road
Newport
South Wales
NP10 8QQ

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I also certify that the application is now proceeding in the name as identified herein.

In accordance with the Patents (Companies Re-registration) Rules 1982, if a company named in this certificate and any accompanying documents has re-registered under the Companies Act 1980 with the same name as that with which it was registered immediately before re-registration save for the substitution as, or inclusion as, the last part of the name of the words "public limited company" or their equivalents in Welsh, references to the name of the company in this certificate and any accompanying documents shall be treated as references to the name with which it is so re-registered.

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Signed

Dated   11 November 2003

By virtue of a direction given under Section 30 of the Patents Act 1977, the application is proceeding in the name of:-

MICROMASS UK LIMITED
Incorporated in the United Kingdom
Atlas Park
Simonsway
MANCHESTER
M22 5PP
United Kingdom

ADP No. 07649676002

INVESTOR IN PEOPLE
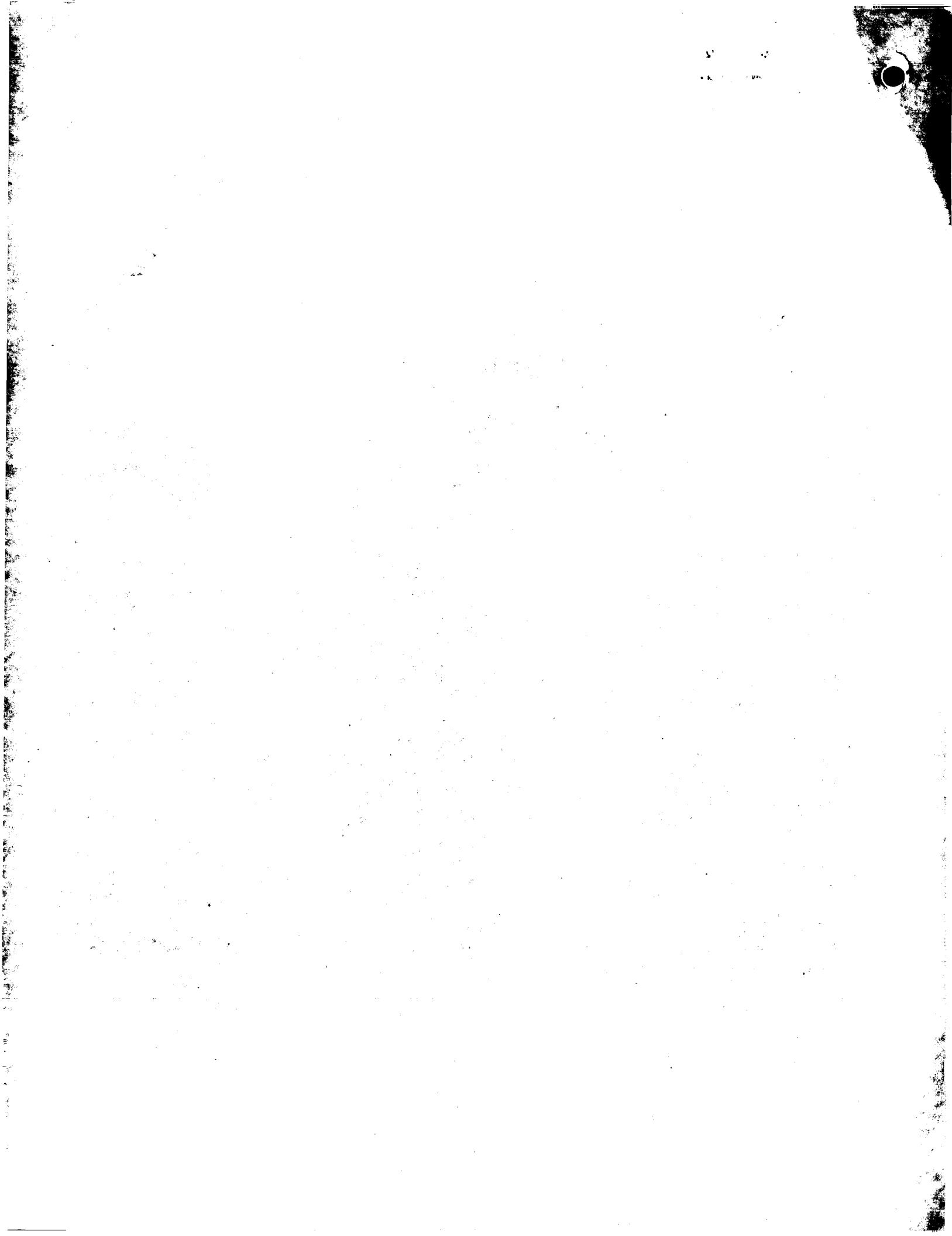
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A
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(See the notes on the back of this form. You can also get an explanatory leaflet from the Patent Office to help you fill in this form.)

The Patent Office
Cardiff Road
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1.	Your reference	85.78857

2.	Patent application number *(The Patent Office will fill in this part)*	**0226017.2**

08N0V02 E761872-1 000027
P01/7700 0.00-0226017.2

3.	Full name, address and postcode of the or of each applicant *(underline all surnames)*	Micromass Limited Floats Road Wythenshawe Manchester M23 9LZ United Kingdom

(PCT) APPLICATION FILED 8 NOV 2002
SECTION 30 (1977 ACT)
02.06.03

Patents ADP number *(if you know it)*   0796102001

If the applicant is a corporate body, give country/state of incorporation   UK

4.	Title of the invention	Mass Spectrometer

5.	Name of your agent *(if you have one)*	Frank B. Dehn & Co.
	"Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)*	179 Queen Victoria Street London EC4V 4EL
	Patents ADP number *(if you know it)*	166001

		Country	Priority application number *(if you know it)*	Date of filing *(day / month / year)*
6.	If you are declaring priority from one or more earlier patent applications, give the country and the date of filing of the or of each of these earlier applications and *(if you know it)* the or each application number			

		Number of earlier application		Date of filing *(day / month / year)*
7.	If this application is divided or otherwise derived from an earlier UK application, give the number and the filing date of the earlier application			

8.	Is a statement of inventorship and of right to grant of a patent required in support of this request? *(Answer 'Yes' if:* a) *any applicant named in part 3 is not an inventor, or* b) *there is an inventor who is not named as an applicant, or* c) *any named applicant is a corporate body.* *See note (d))*	Yes

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10. If you are also filing any of the following,
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          Translations of priority documents –

          Statement of inventorship and right –
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          Request for preliminary examination –
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               (*please specify*)

11.   I/We request the grant of a patent on the basis of this application.

                                             Signature   Date 8 November 2002

12. Name and daytime telephone number of
     person to contact in the United Kingdom   P.M. Jeffrey
                                               01273 244200

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*After an application for a patent has been filed, the Comptroller of the Patent Office will consider whether publication
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78857

Swept Mass Acceleration Guide (SMAG)

Background of Invention

US Patent 5,140,158 "Method for discriminative particle selection" describes a means for separating ions by utilising a travelling potential hill created by a series of quasi-static electric potential hills. The envisaged application was isotope enrichment of (for example) Uranium for nuclear power plants. This invention consisted of a series of rings to which a pulsed voltage was applied to each in sequence creating the travelling potential hill. Ions that are initially at rest which interact with a potential hill of sufficiently high amplitude Φ_E travelling with velocity v_0 will be reflected with a velocity $v_r = 2\,v_0$. If the hill is not of sufficient amplitude then ions will go over the potential barrier unaffected with a final velocity of zero. The criteria for reflection depends on Φ_E, v_0, ion Mass M, and charge Ze. If $Mv_0^2/2 > Ze\Phi_B$ then the hill will impart no kinetic energy to the ion and leave it behind. If $Mv_0^2/2 < Ze\Phi_E$ then the ion will be reflected by the hill attaining the velocity v_r. The analysis of resolution of ion separation in this device is strictly one-dimensional but takes no account of the radial variation in electric field caused by the ion optics that create it. It is the object of the present invention to overcome the shortcomings of the aforementioned device by constraining the ions radially using RF confinement.

Description of invention

Consider a ring set such as is envisaged in US Patent 5,140,158, then the travelling wave is simulated by applying a pulsed voltage to each ring for a finite time before moving on to the next ring. The more rings there are per unit length of the device the closer a continual travelling wave is approximated. The wider the spacing the greater is the axial extent of the potential hill. The electric field at an instant in time is determined by the difference of potential between the particular ring that has the driving potential applied to it and its neighbours. By symmetry considerations alone it is clear that along the optic axis of the device the electric field has no radial component. As one moves away from the axis in a radial direction out towards the electrodes significant radial field components appear and also the field component along the axis also changes in magnitude. Figure 1 shows the contours of equipotential for a ring guide of 5mm diameter and 1mm ring pitch with a potential of 500V applied to the centre ring. Such distortion in electric field causes ions to be accelerated in the radial as well as axial direction. The variation in axial field with radius causes deterioration in the resolution of the device. The size of the potential hill is now a function of the radial position so the device can no longer select a unique mass to charge. Ions may acquire radial components so great that they collide with the electrodes themselves and are lost. Figure 2 shows typical ion trajectories from a device as described in Figure 1. It is the aim of the present invention to compensate for this radial distortion by providing an opposing force acting towards the centre of the device which increases in magnitude according to radial displacement. In this way the ion beam occupies a small enough radial spread such that the resolution of the device is not compromised by the nonlinearity of the field. Ion losses are also reduced as the ions are prevented from leaving the area of confinement around the optic axis of the device.

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Radio Frequency (RF) ion guides are commonly used for confining and transporting ions. All such ion guides use an arrangement of electrodes with an RF voltage applied between neighbouring electrodes such as to produce a pseudo-potential well or valley. This pseudo-potential well can be arranged to confine ions, and may be used to transport ions by acting as an ion guide. Its use as an ion guide is well known, and can be very efficient. These RF ion guides may be quadrupole, hexapoles or octapoles (collectively known as multipoles) or of the stacked ring type whereby opposite phases of the RF voltage are applied to adjacent rings. The stacked ring geometry is the same as that described in the electrostatic device of US Patent 5,140,158 and so application of an RF field to the existing geometry provides radial confinement of the ions with the benefits previously described. The RF field produces an "Effective Potential" which is related to frequency of the confining RF and the ion guide geometry itself and is given by:

$$V^* = \frac{q^2 V o^2}{4m\Omega^2 z_o^2}\left[I_1^2(\hat{r})\cos^2\hat{z} + I_o^2(\hat{r})\sin^2\hat{z}\right]/I_o^2(\hat{r}_o)$$

$$\hat{r} = r/z_o$$
$$\hat{r}_o = r_o/z_o$$
$$\hat{z}_o = z/z_o$$

where Vo is amplitude of the applied RF voltage of angular frequency Ω, m is mass and q is charge, and I_1 & I_0 are modified Bessel functions. The r_o & z_o parameters are as defined in Figure 3.

It can be seen then that the addition of an RF field with adjacent electrodes in antiphase leads to confinement of the ions around the optic axis without changing the mechanical construction. It should be noted that such a travelling potential hill device would be possible to construct using segmented quadrupoles (or any multipole) such that each segment was capable of separate DC potential being applied to it. The operation of the device as a mass analyser can now be described in more detail.

Operation of Invention

Consider now a stacked ring ion tunnel device (at a pressure such that the probability of an ion experiencing a collision while traversing its length is negligible) filled with ions such as may be generated by an electrospray or MALDI ion source. If the end plates of the tunnel have a slight positive voltage with respect to all the central plates then ions will be trapped in the device unable to surmount the potential barrier. After a certain time equilibrium will be reached where ions of all masses are distributed along the length of the device [Figure 4]. If a voltage is then applied to the first electrode in the tunnel adjacent to one of the end plates the ions will be pushed down the device [Figure 5]. The electric field caused by the applied voltage rapidly decays to a negligible value just a few electrode spacings. The voltage is then rapidly switched to the next electrode and an ion that had enough time to travel one electrode spacing will experience the same force and move again. Those ions of high mass may not have time to travel far enough to see the influence of the voltage when it switches

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to the next electrode and will be left behind. The voltage travels down the device from electrode to electrode "sweeping" those ions with a low enough mass to follow it. The device acts as a low pass filter in that ions with masses below a chosen value can be ejected from the tunnel whilst the rest remain trapped in the device [Figures 6 & 7]. The sweep time of the device Tsweep may be then decreased to select a slightly higher low mass cut off ejecting those ions which have masses between the two cut off points. By gradually reducing the sweep time a complete mass "scan" may be built up until the device is empty. Another way to scan the device is to increase the voltage progressively with each sweep collecting ions of ever-increasing mass in the same way.

The mode of operation described above builds up a mass spectrum by a series of low pass experiments. Isolation of a particular range of masses i.e. bandpass operation may be achieved by employing a two stage device [figure 8]. Firstly ions with Masses < X are passed through the device into a second empty stage [Figure 9]. A second travelling wave may then be sent in the reverse direction sweeping ions back into the first stage [Figure 6]. This reverse sweep is of a higher voltage so that the required mass range is left behind in the second stage [Figure 10]. Note that figure 9 shows the potential hill for the reverse sweep increased by approximately a factor of nine. This is because the relative velocity between the hill and the ion has increased from v_0 (the hill velocity) to $3v_0$ as the ion is accelerated to $2v_0$ by the hill during the first pass and then approached by a second hill at $\sim v_0$ again. The potential required to just prevent an ion from traversing though it is proportional to the relative velocity squared hence the factor of nine.

Advantages over prior art

1) High duty cycle & flexible timescale of ion ejection:

The new device can operate at 100% duty cycle as it is able to eject only those ions of desired mass while storing the rest for further analysis this is in contrast to a conventional axial TOF whereby ions of all masses are pulsed into a drift tube and sequentially detected.

2) Folded geometry:

As ions may be send backwards and forwards within the SMAG device enabling band-pass operation to be achieved.

3) High sensitivity:

The current invention will exhibit higher sensitivity than the previous device. This is because ion losses due to the radial field components are minimised by the confining action of the effective potential to the central optic axis.

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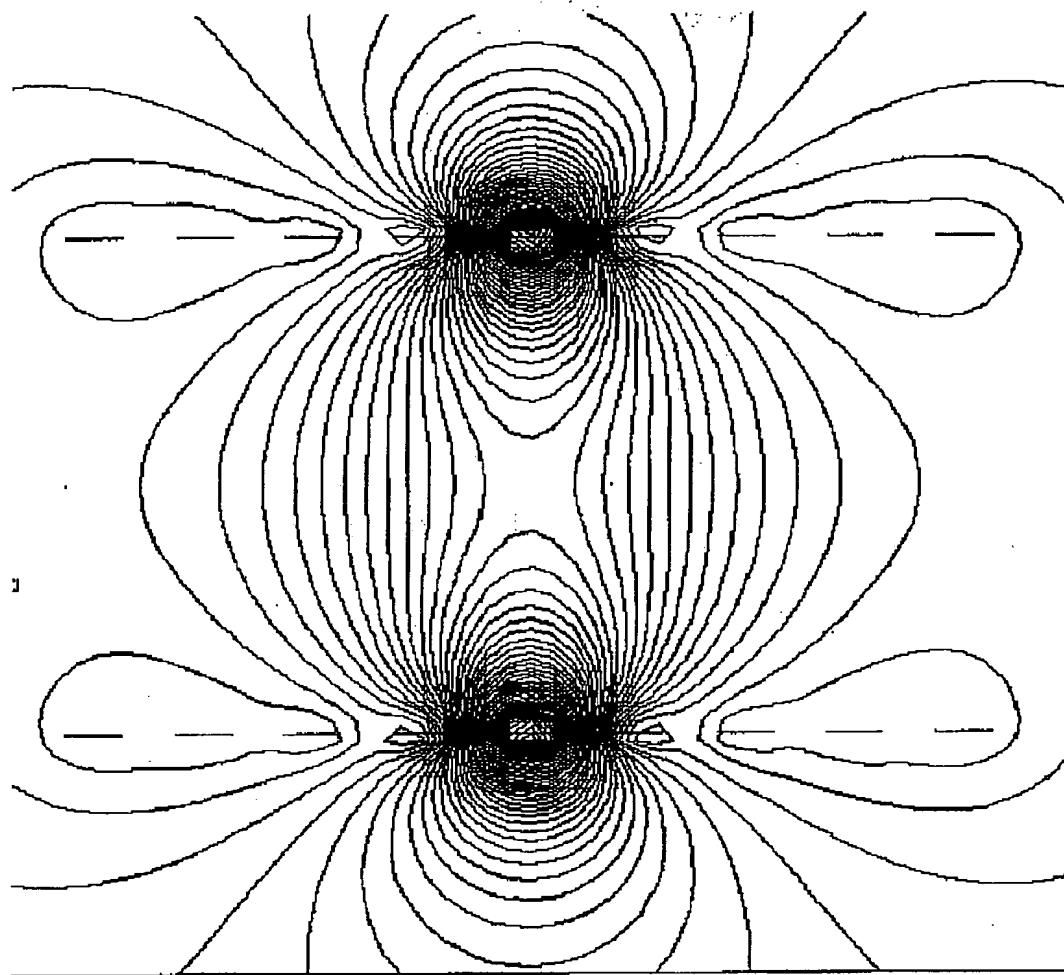
Figure 1. Contours of equipotential for a segmented ring guide 5mm diameter, 1mm ring pitch with 500V on the central electrode.

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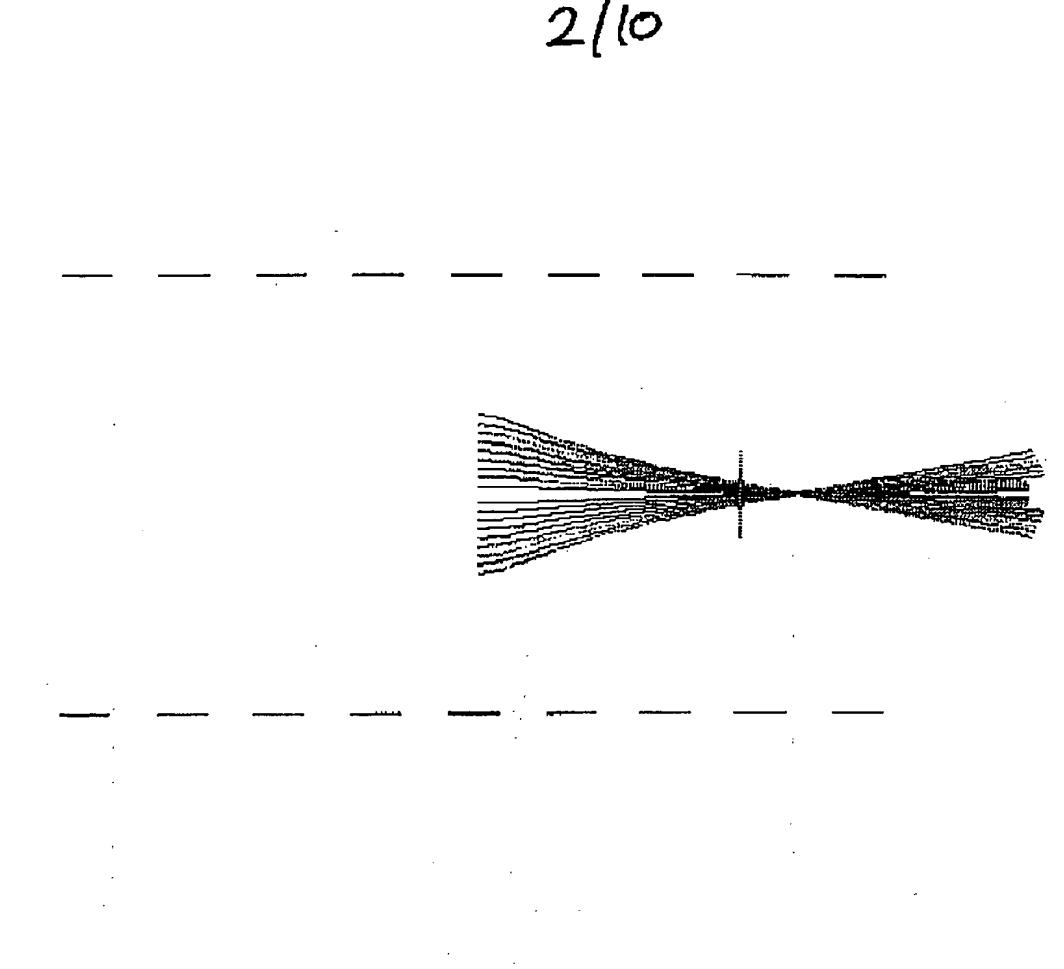
**Figure 2** Typical ion trajectories from a segmented ring travelling potential hill.
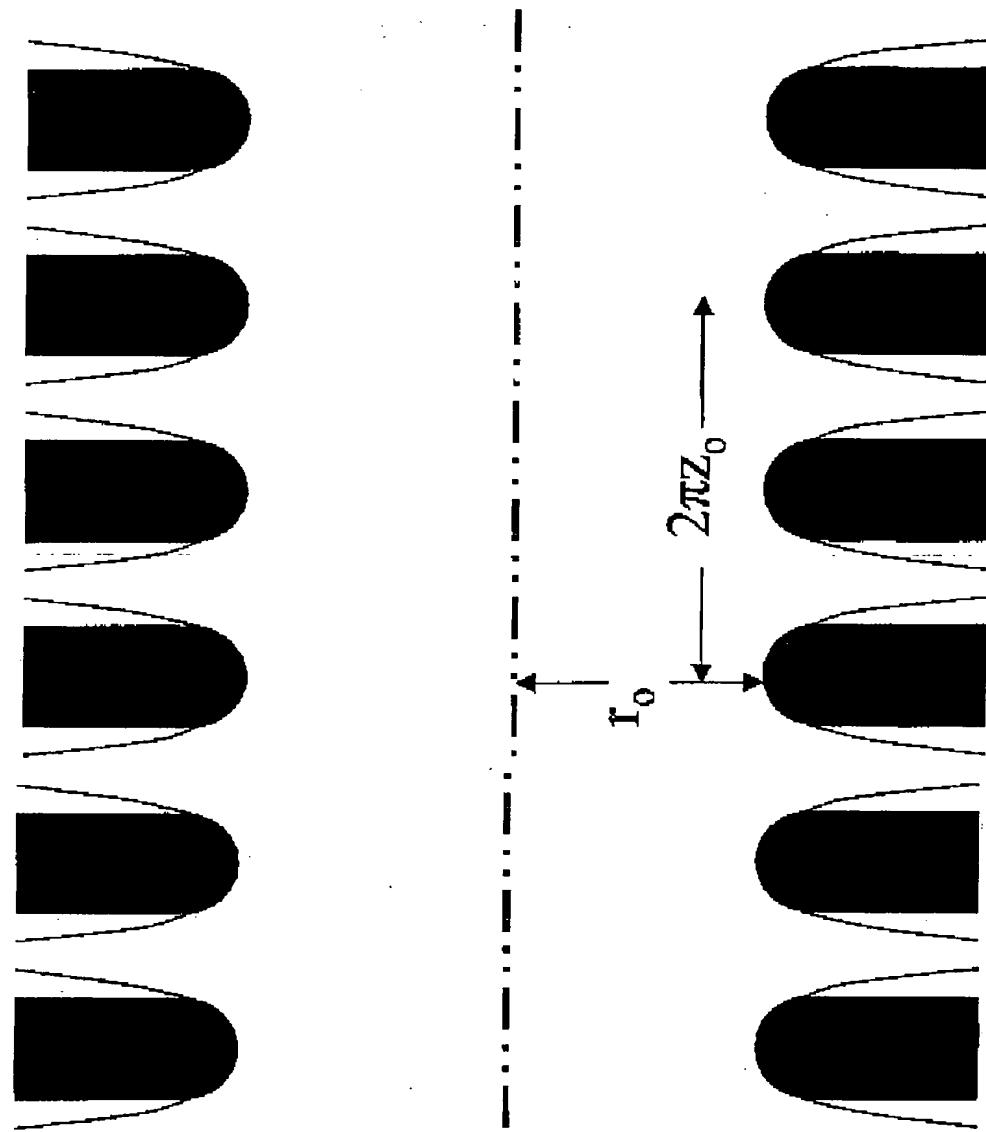
Figure 3 Rotationally symmetric ring guide in r & z co-ordinates
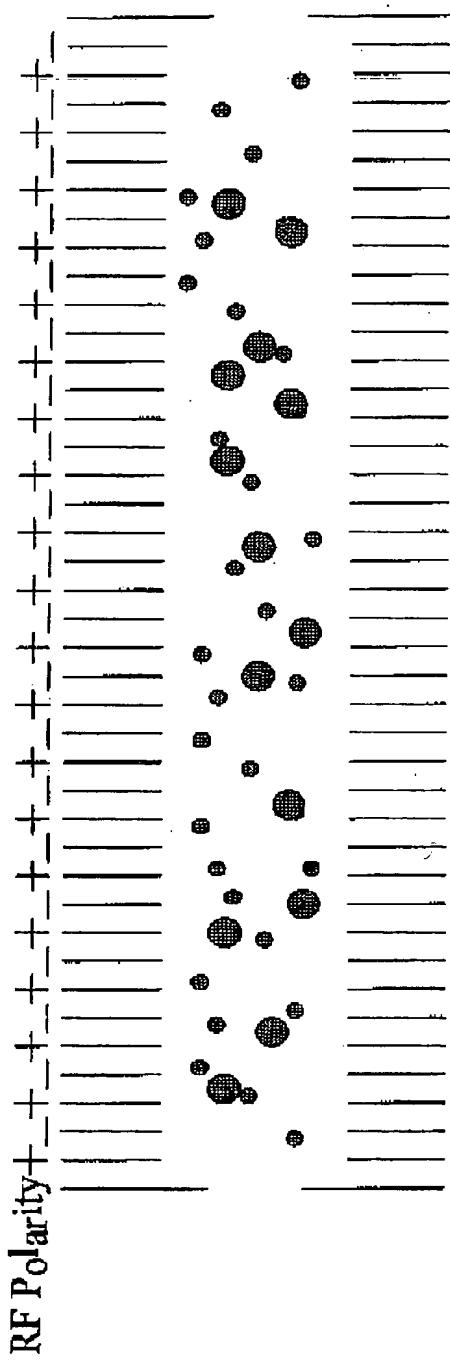
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Figure 4. Equilibrium in the tunnel

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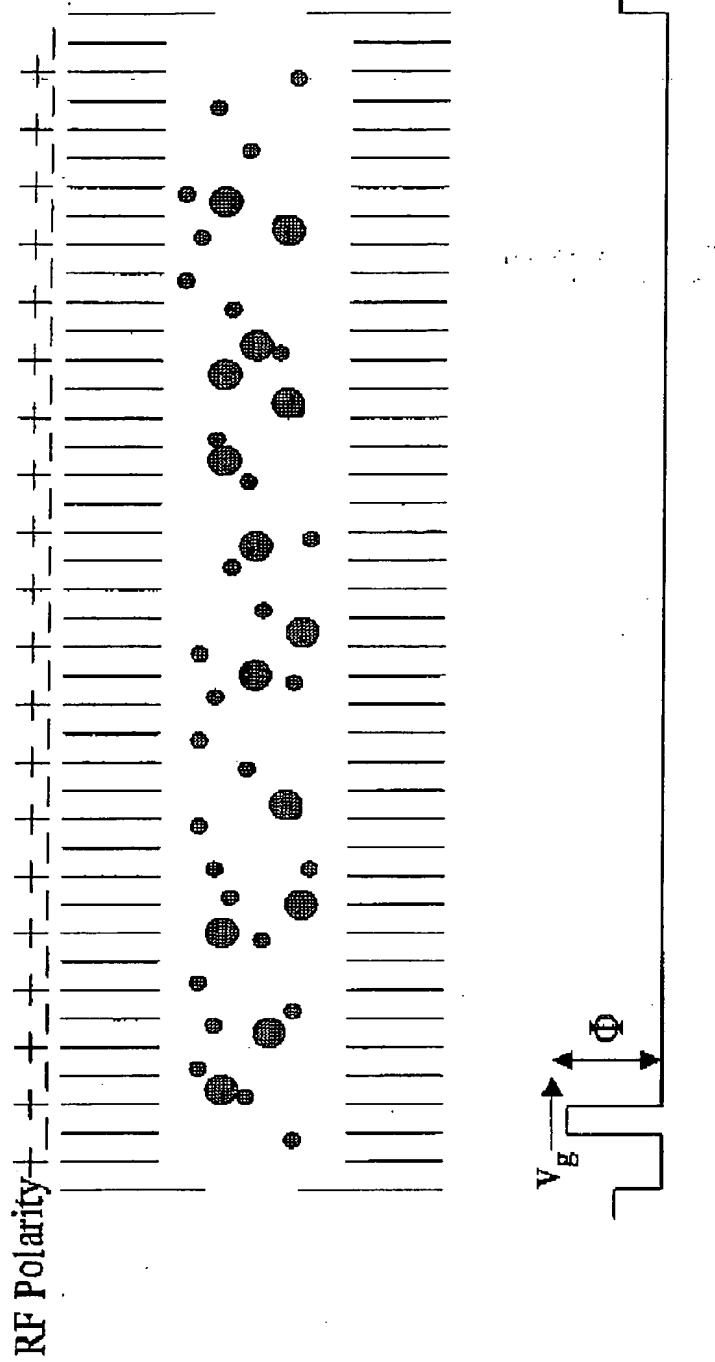
**Figure 5.** Travelling wave begins at one end of device
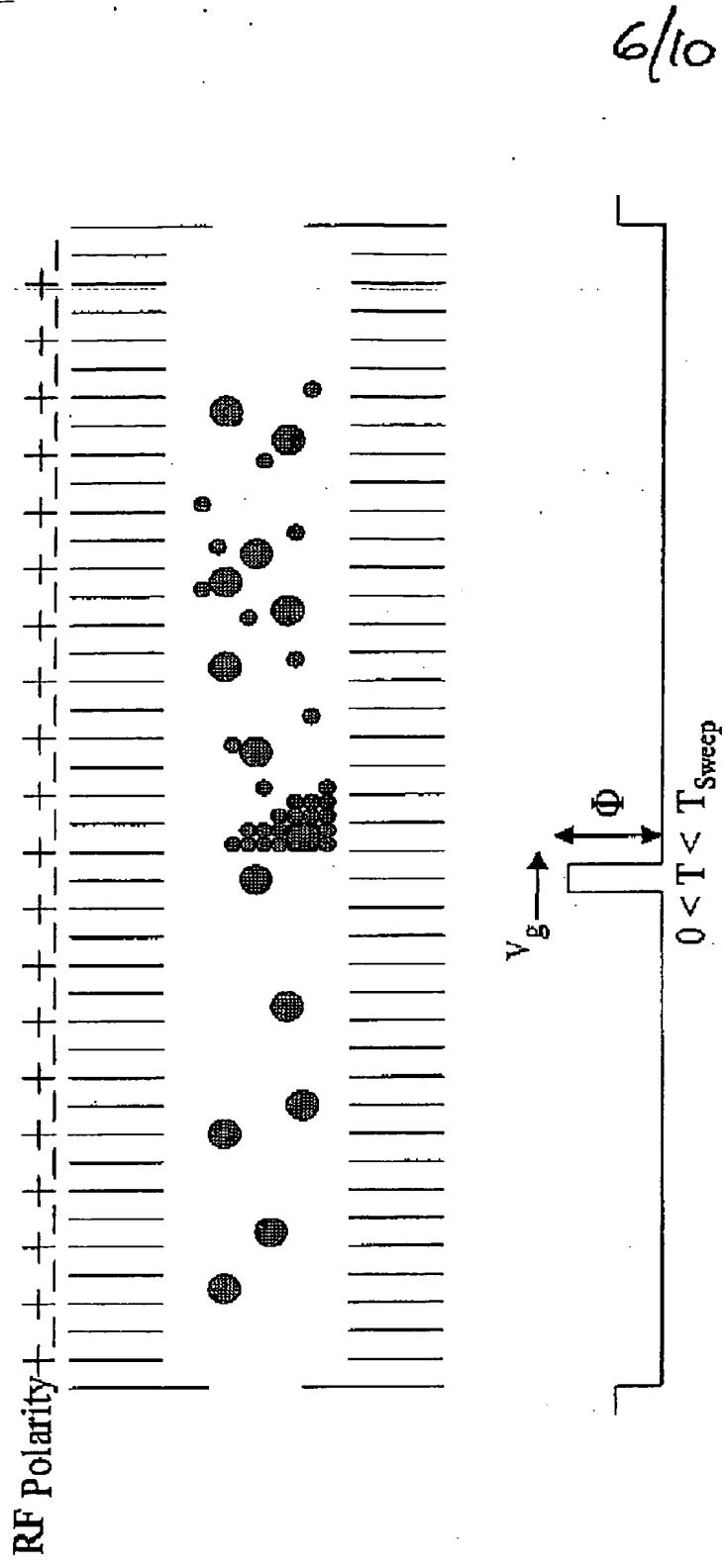
**Figure 6.** Travelling wave sweeping low mass ions and leaving high mass behind

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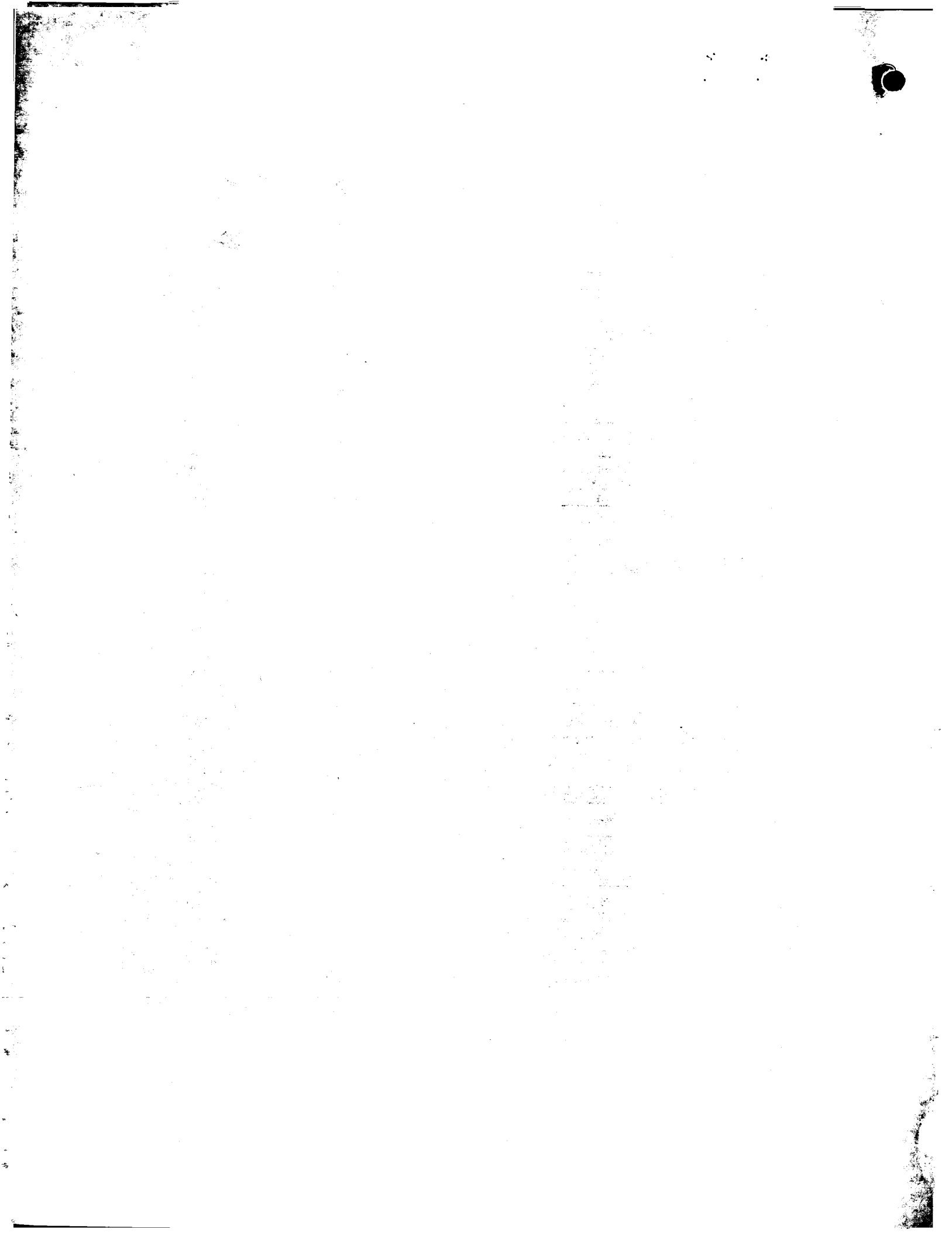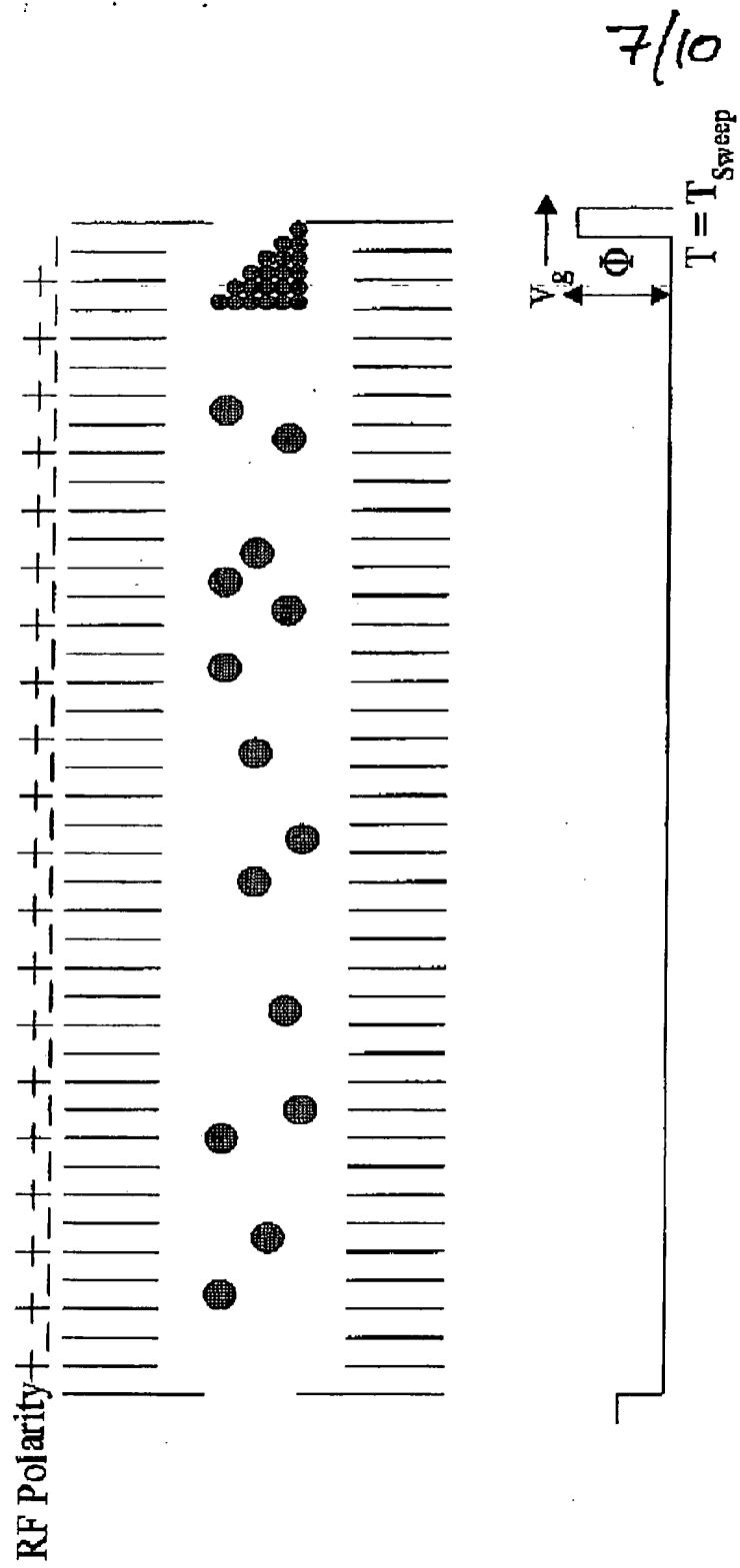
Figure 7. All low mass ions swept and ejected from device

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RF Polarity

V_g

Φ
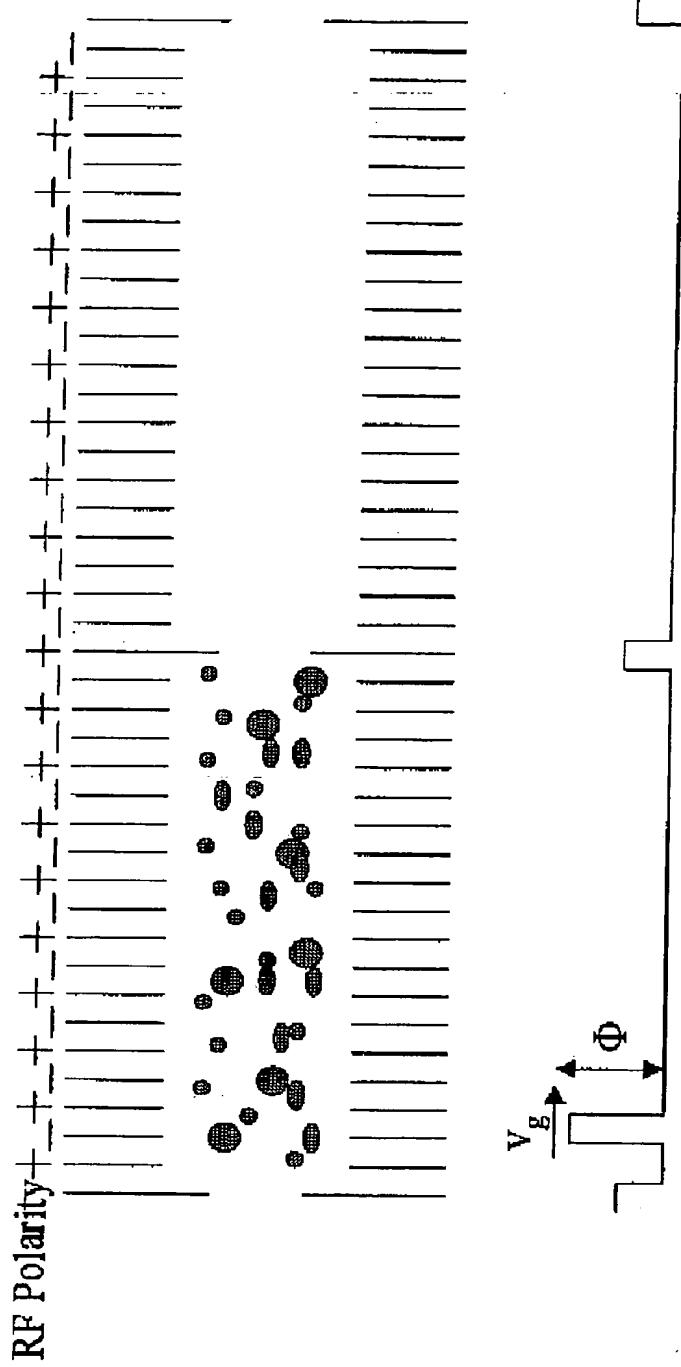
Figure 8. Split device at equilibrium
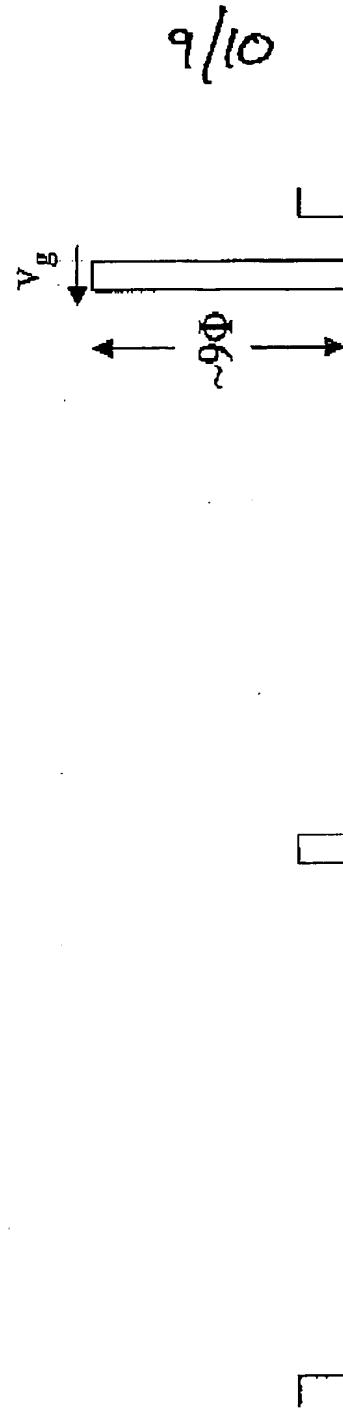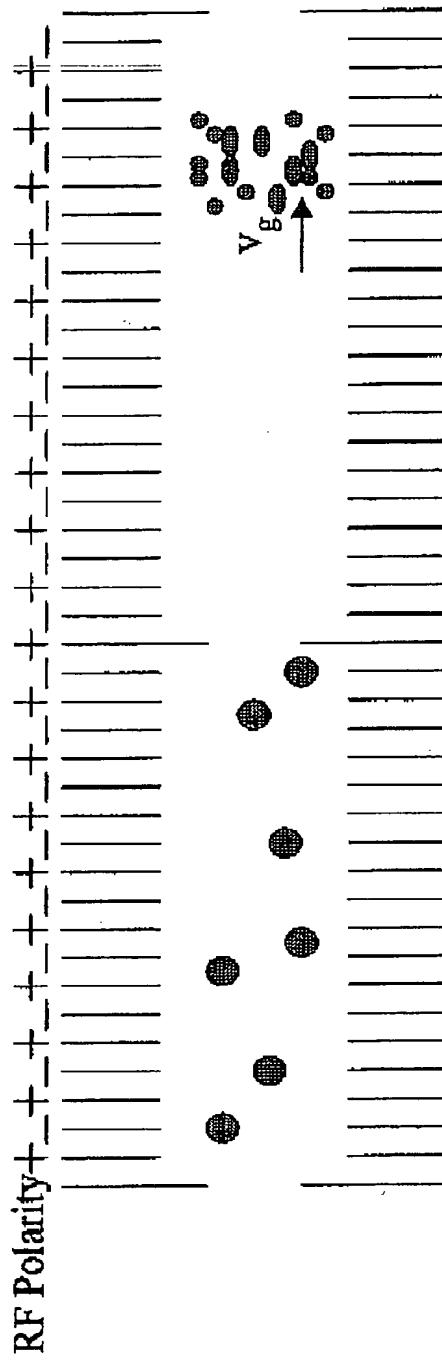
Figure 9. Low mass ions swept into second stage of device, wave direction reversed and intensity V_g increased by approx. nine fold.
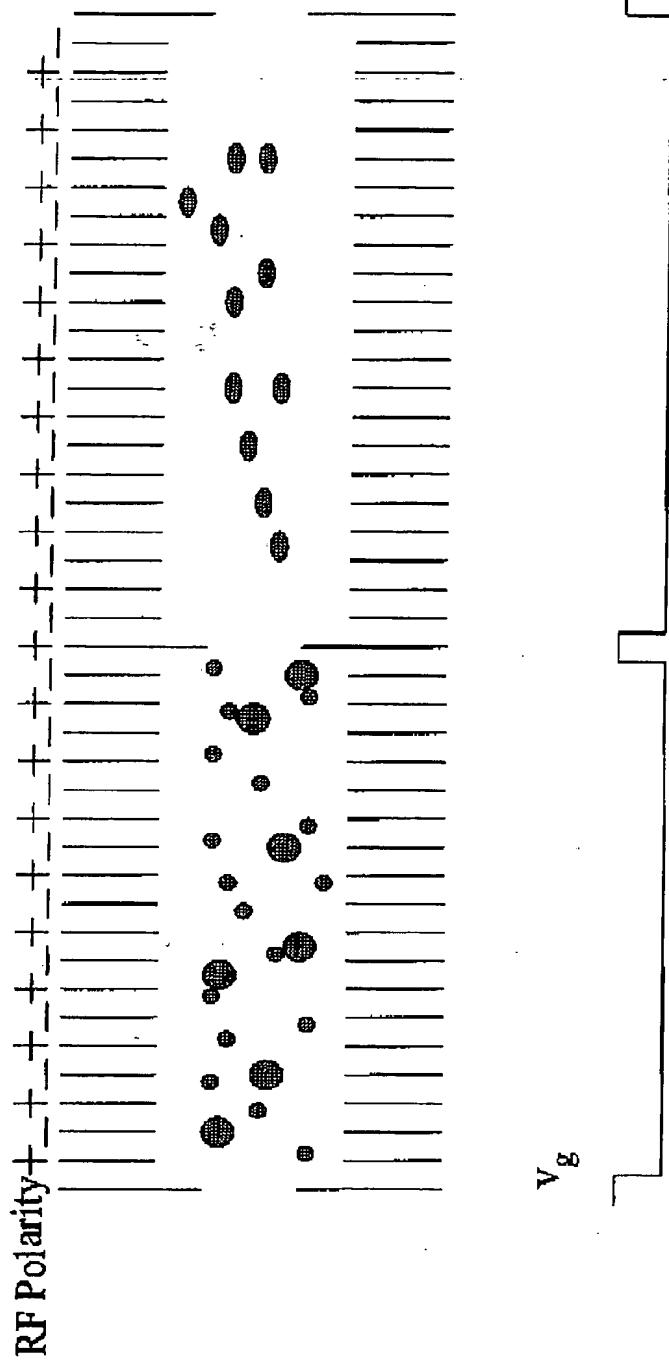
Figure 10. Intermediate mass left behind in second stage (bandpass operation).